# IMPROVING THE GALVANIC SERIES FOR DESIGN

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# One of Many Galvanic Series Available



What's the corrosion rate?

Where's Zn-Ni?

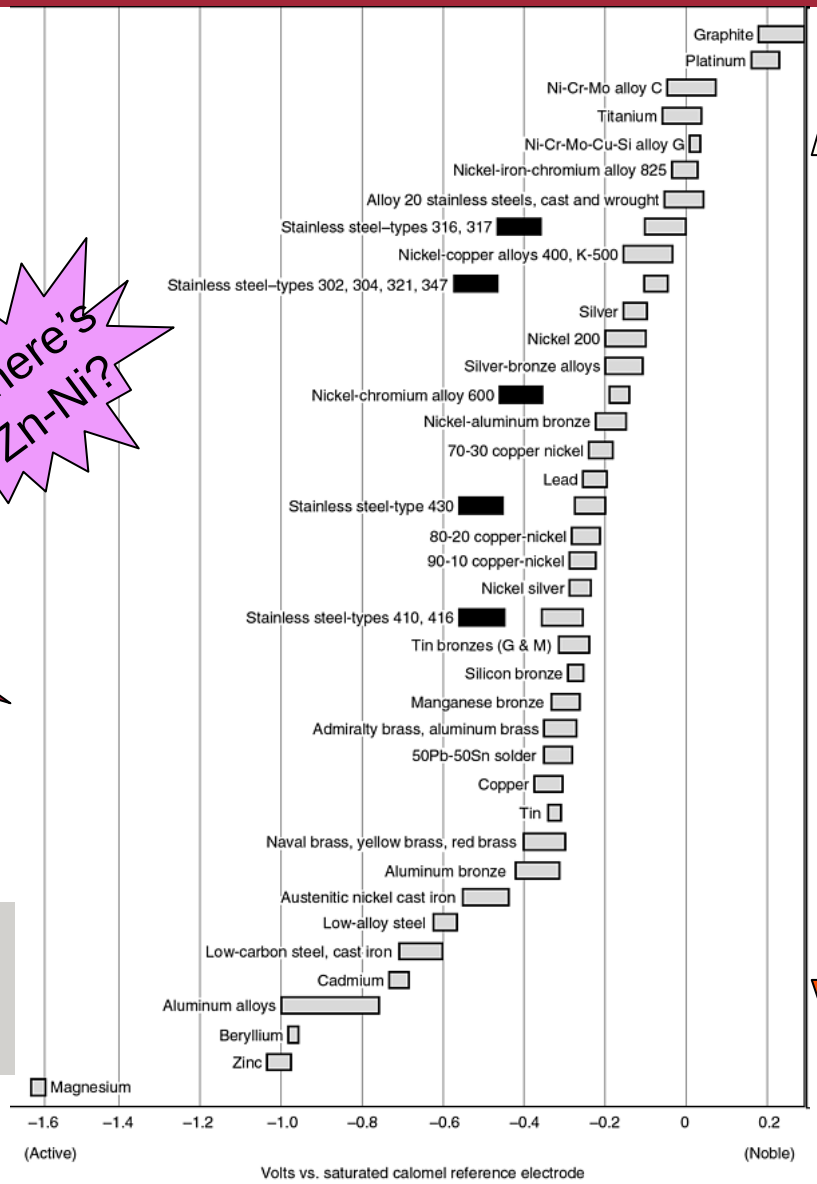
Why is this different from the EMF series?

This isn't my environment

Where's my HVOF?

Which is the cathode?

Isn't this upside down?




**Noble**

**Active**

Metals in flowing seawater

# What's Our Concern?



- **Designer Concerns**
  - **Metal compatibility with environment**
  - **Galvanic coupling of dissimilar metals**
  - **Adding an inorganic coating**
  - **Adding an organic coating**
  - **Minimizing service failures**
- **Production and Maintenance Concerns**
  - **Scheduling Inspections**
  - **Replacing Designs that don't work**
  - **Material and Design Trades**
    - **Reduce costs**
    - **Reduce maintenance**
  - **Allowing Substitutions**

# Technical Needs



- **What we do already—**
  - **Use "Galvanic Series"**
  - **Qualitatively rely on "tribal knowledge" & handbooks**
  - **Conduct Laboratory Tests**

- **What we want to do—**
  - **Use Engineering Tools to Propose Engineering Solutions**
    - **Design tools require quantitative data**
  - **Quantify severity of corrosion on all geometries**
    - **Coupled finish on substrate of detail part**
    - **Coupling of detailed parts of different materials**
  - **Reduce/Eliminate Laboratory Tests**

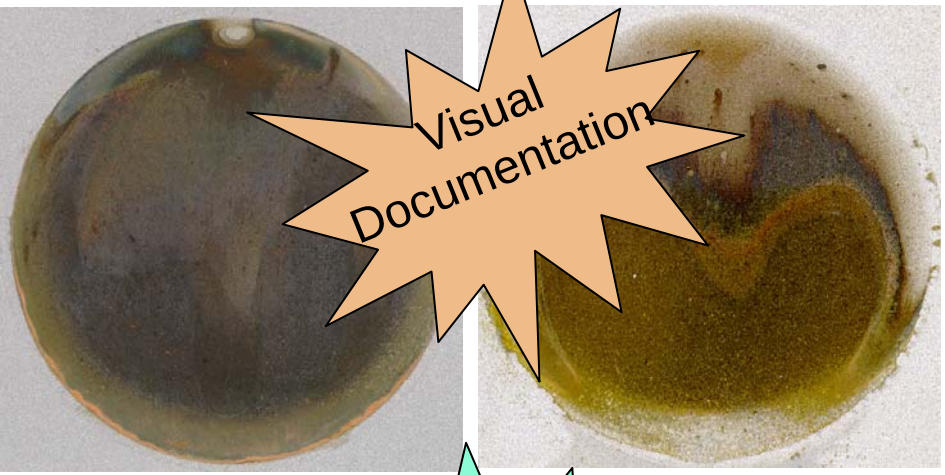
# Approach Methods

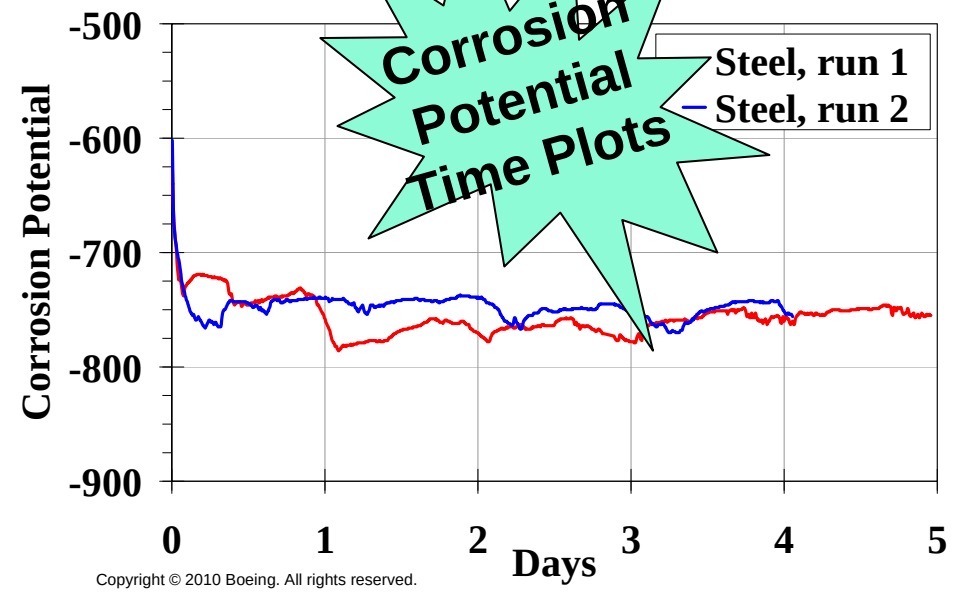


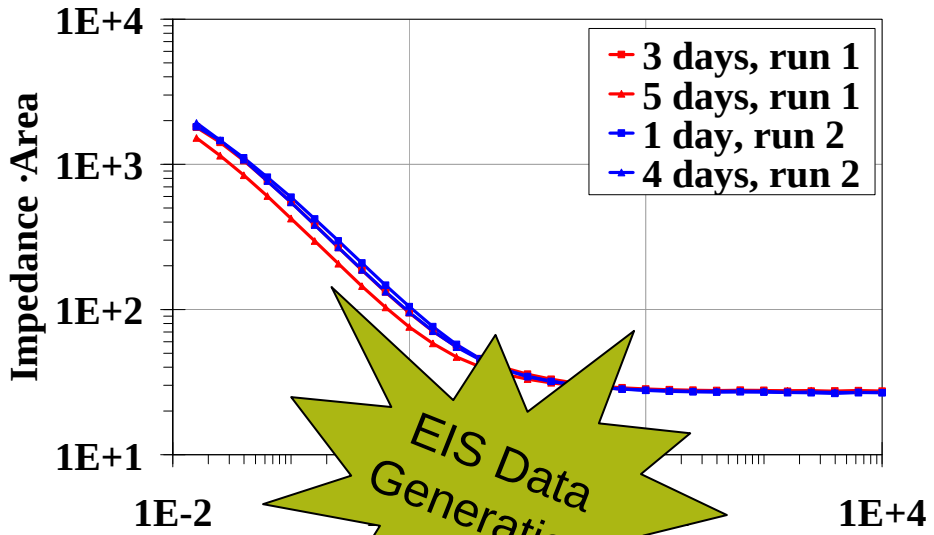
- **Galvanic Series Chart for Designers**
  - **Establish Steady State Corrosion Potential**
  - **Measure Corrosion Rate**
  - **Generate anodic and cathodic polarization curves**
- **Predict Galvanic Coupling Effects on Geometries**
  - **For 1-D(imensional) Quick-Look**
    - **Superimpose polarization curves**
  - **For 2-D & 3-D mapping**
    - **Work with industrial partners for computer application solutions**
      - **Utilize polarization curves**
      - **Solve potential and current distribution equations for geometry**

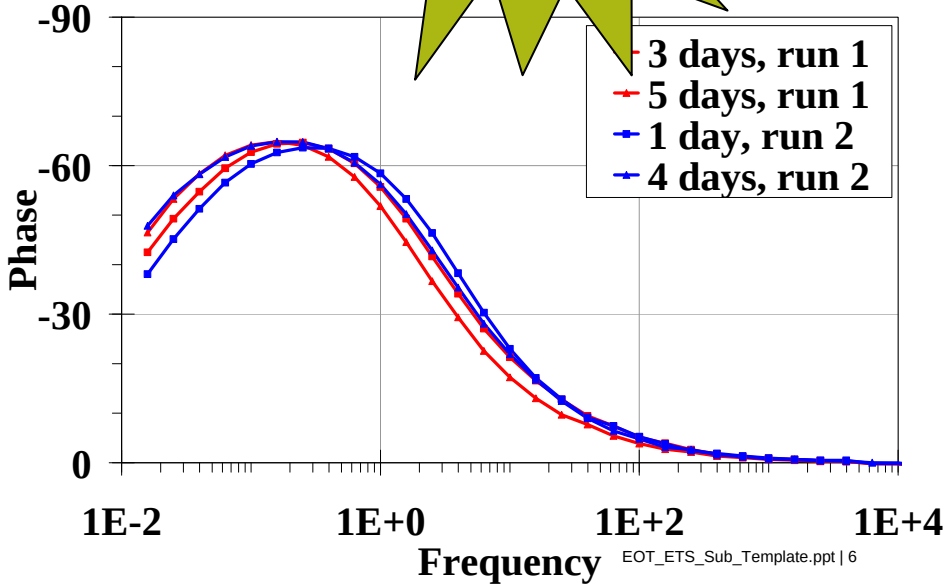
# Initial Data Acquisition –Steel Example





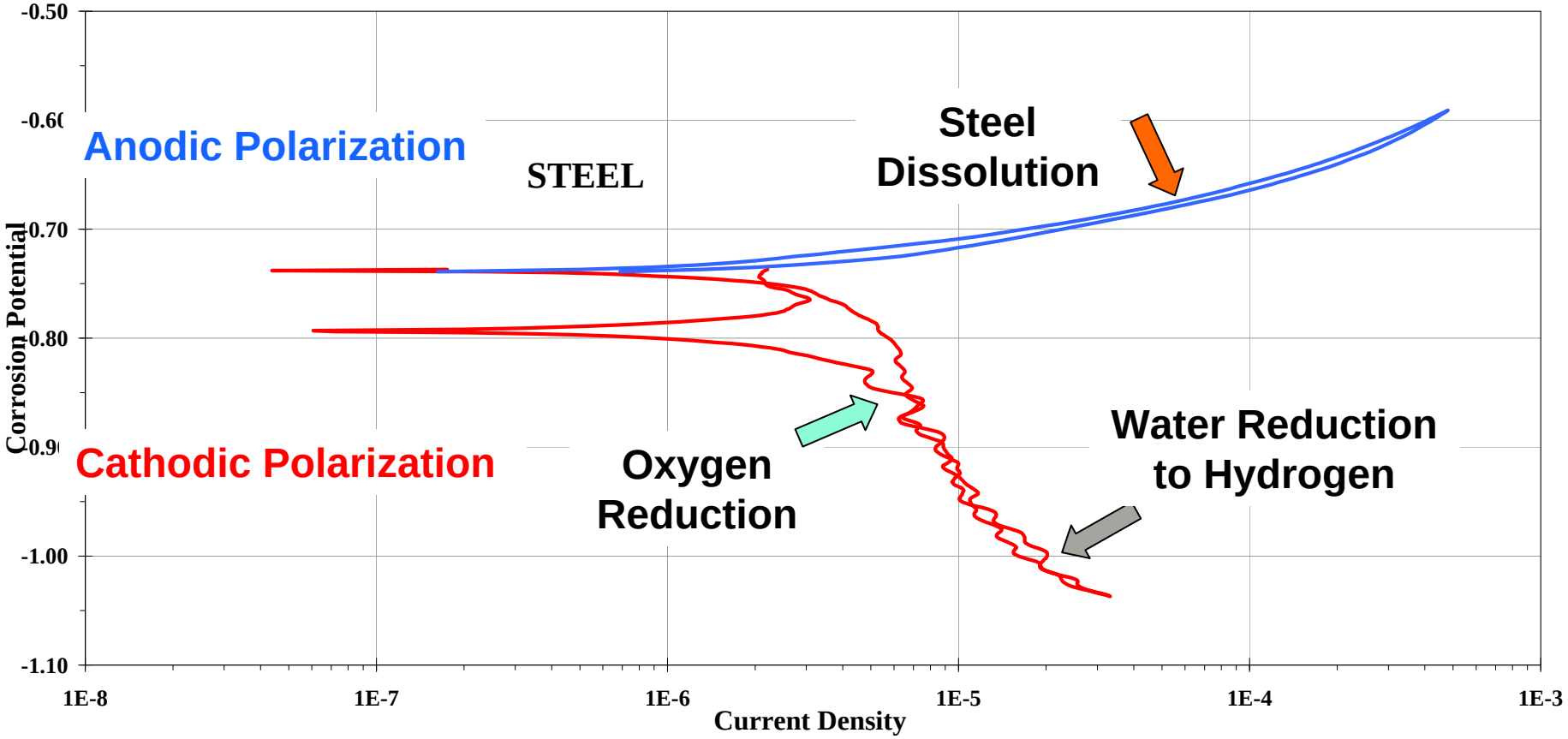



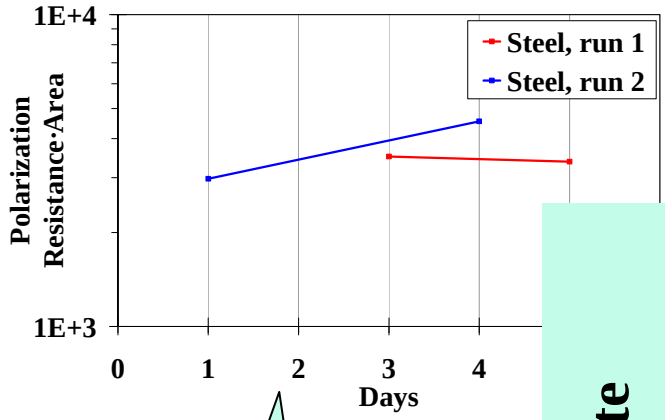
# Polarization Curves of Steel in Salt Water

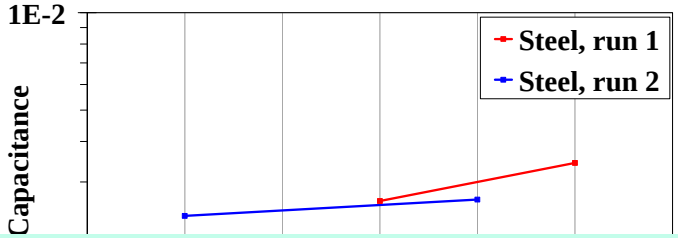




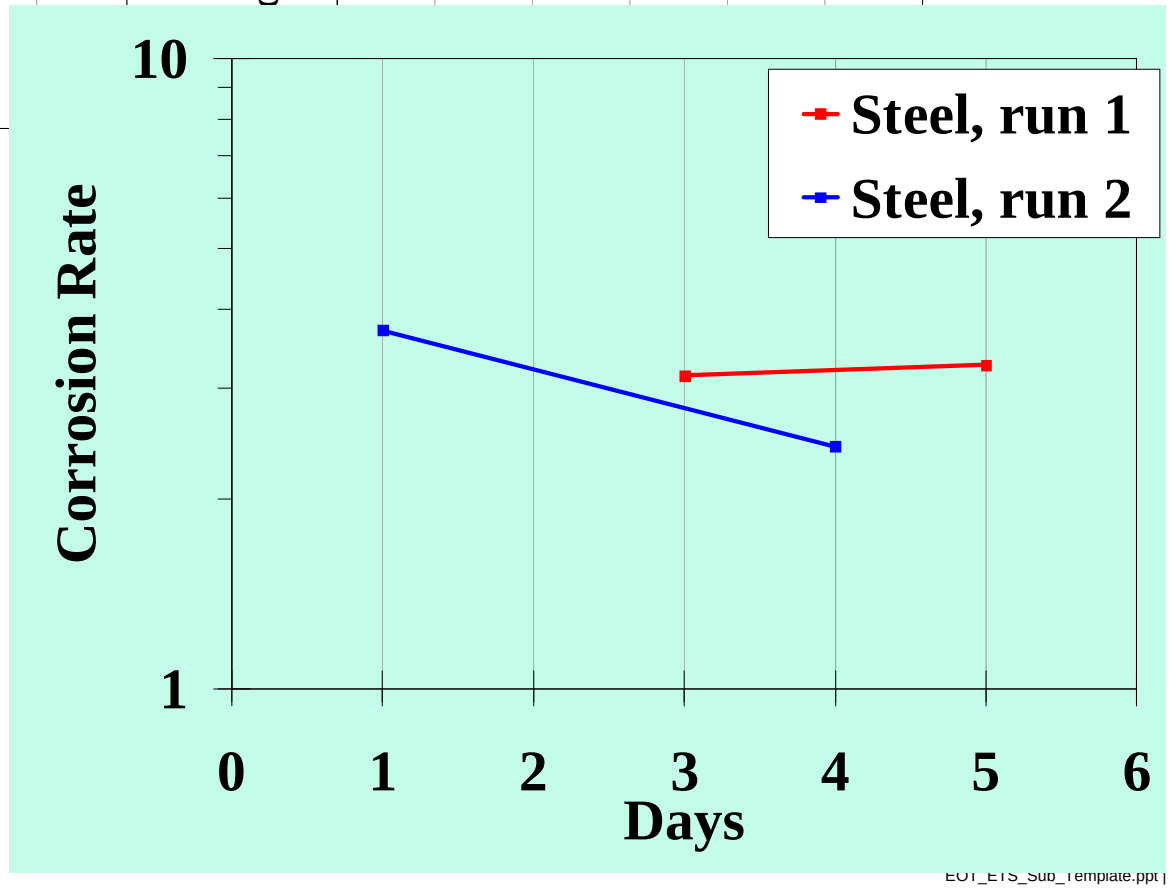
# Data Analysis and Results





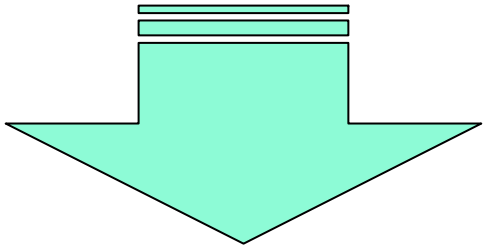

Corrosion Rate Time Plots



# Boeing's Work to Date



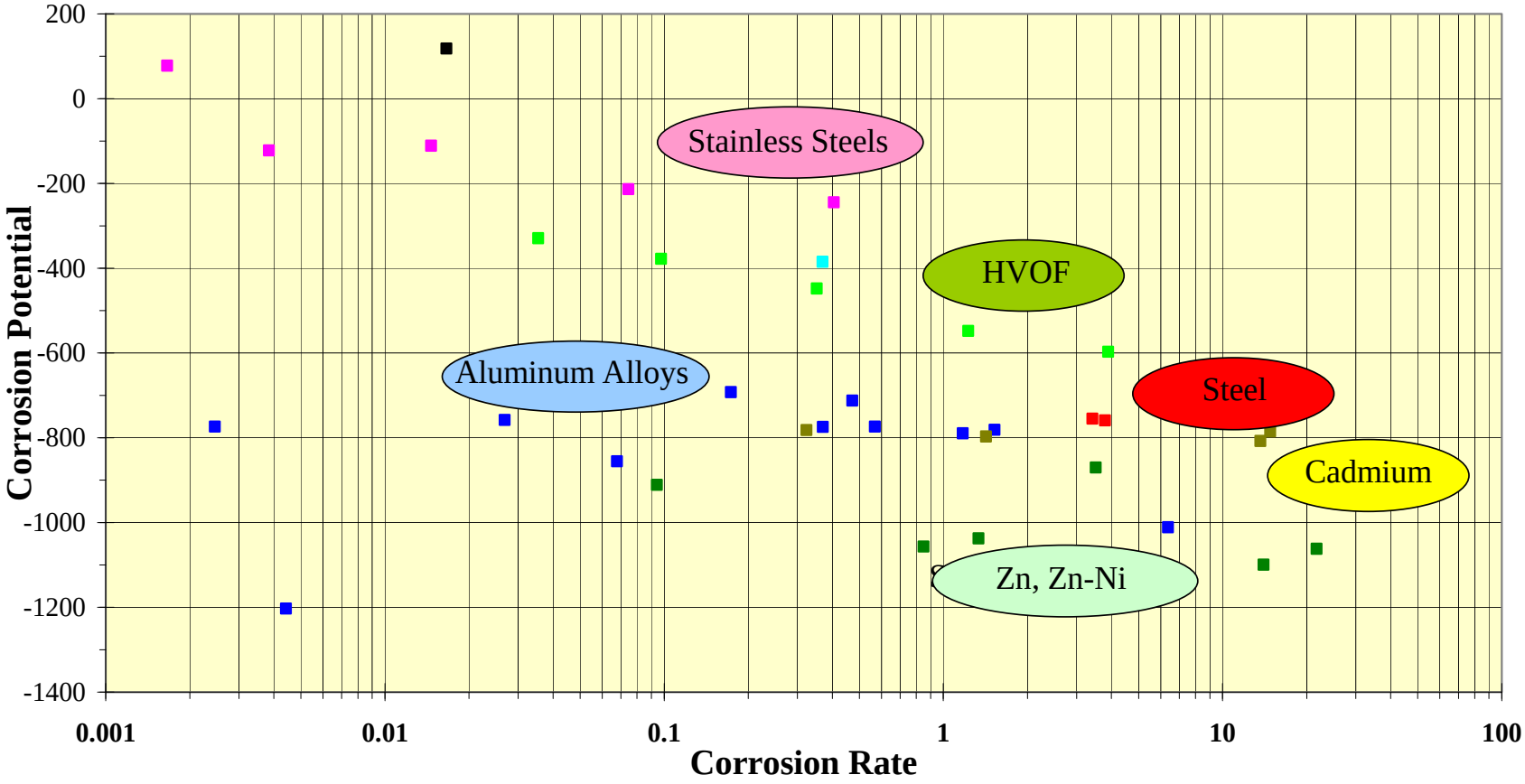
- **Generated steady-state Corrosion Potentials**
- **Generated steady-state Corrosion Rates**
- **Generated some Polarization Curves**



- **Initiated Next Generation Galvanic Series with 1-D Quick-Look**

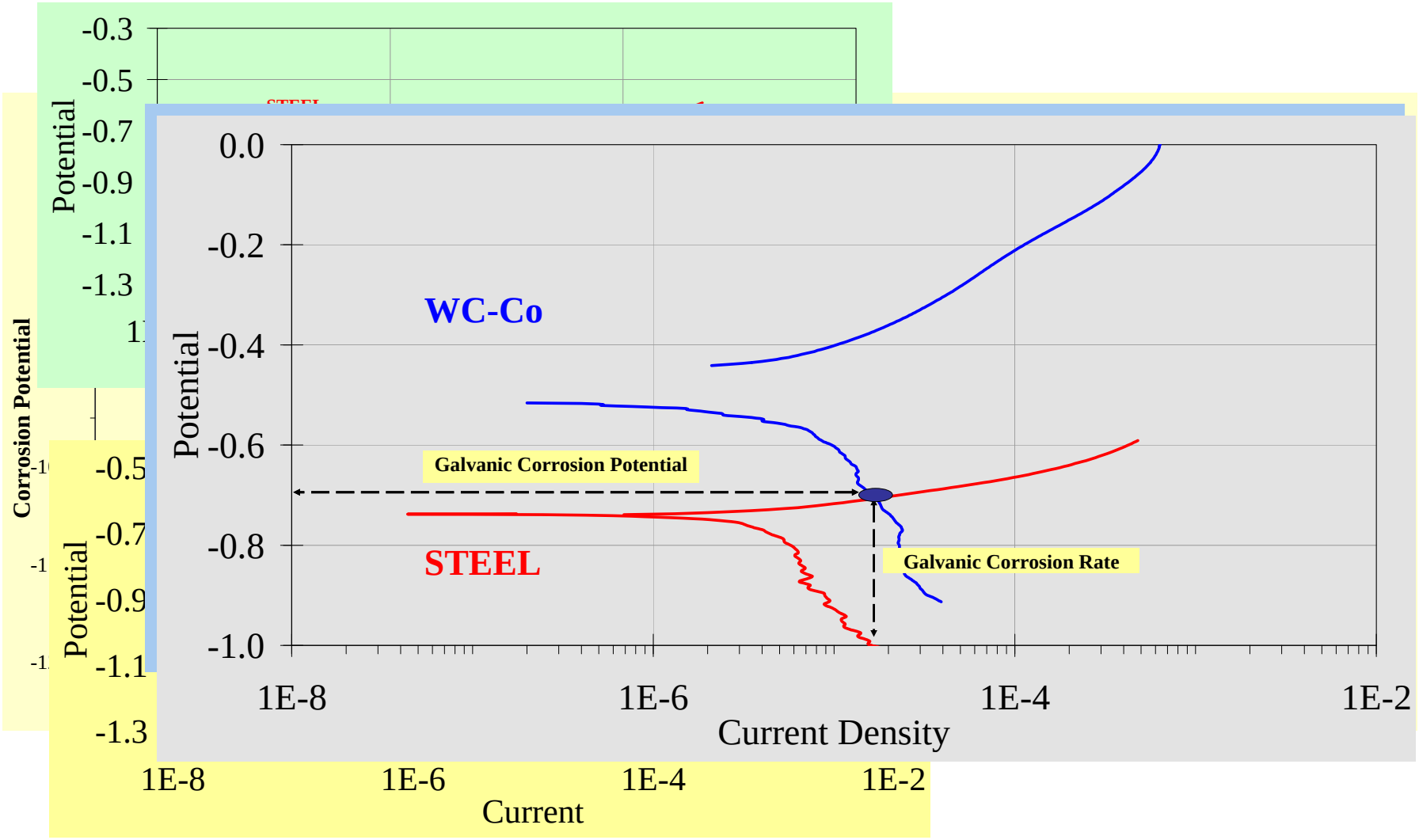
# Next Generation Galvanic Series





# Next Generation Galvanic Series of Steel and Finishes with 1-D Quick-Look





# So Far



- **Established an initial protocol**
  - **Materials and finishes placed on NG Galvanic Series**
  - **Some polarization curves utilized for 1-D Quick-Look**
- **Need an industry wide protocol to address materials, finishes, and geometries**
  - **Complete NG Galvanic Series with 1-D Quick-Look**
  - **Implement polarization curves into 2-D and 3-D design**
  - **Verify experimentally corrosion severity mapping**
  - **Funding to extend DoD relevant coating systems**
- **Into the future**
  - **Investigate crevice corrosion environments**
  - **Include organic coatings**

# BACKUP

# Road Forward – Phase I Methodology



- **Establish industry working group**
  - **Identify objectives**
  - **Down select test variables and procedures**
    - **Environments of interest**
    - **Extent of variations of metals, alloys, and finishes**
    - **Electrochemical tests**
    - **Specimen geometries**
    - **Test Procedure criteria**
    - **Data Analysis**
- **Conduct Electrochemical Testing on Bare Alloys**
- **Conduct Galvanic Corrosion Analysis**
  - **Generate NG Galvanic Series with 1-D Quick-Look**
    - **Validate 1-D Quick-Look galvanic corrosion predictions**
  - **Initiate 2-D and 3-D galvanic corrosion prediction mapping**

# Road Forward – Phase II Execution



- **Establish a NG Galvanic Series with 1-D Quick-Look capabilities for Design**
  - **Complete electrochemical testing for remaining alloy families and finishes**
- **Develop and execute a test plan to validate predictions for 2-D and 3-D geometries**

# Next Generation Galvanic Series